CONSERVATION SCREENING CURVES TO COMPARE EFFICIENCY INVESTMENTS TO POWER PLANTS: APPLICATIONS TO COMMERCIAL SECTOR CONSERVATION PROGRAMS

Jonathan Koomey, Arthur H. Rosenfeld, and Ashok Gadgil
Center for Building Science
Lawrence Berkeley Laboratory

This paper describes a simplified methodology to compare supply and demand-side resources. The *screening curve approach* supplements with load shape information the data contained in a supply curve of conserved energy. In addition, a screening curve contains information on competing supply technologies, such as annualized capital costs, variable costs, and cost per delivered kWh. The information in the screening curve allows policymakers to promptly and conveniently compare the relevant parameters affecting supply and demand-side investment decisions.

While many sophisticated computer models have evolved to account for the load shape impacts of energy efficiency investments, this sophistication has, by and large, not trickled down to spreadsheet-level or "back-of-the-envelope" analyses. Our methodology allows a simple summary of load shape characteristics based on the output of the more complicated models. It offers many advantages, principal of which is clarity in analyzing supply and demand-side investment choices.

This paper first describes how supply-side screening curves have been used in the past, and develops the conceptual tools needed to apply integrated supply/demand screening curves in the least-cost utility planning process. It then presents examples of supply-side technologies and commercial sector demand-side management programs, and plots them on representative screening curves.

INTRODUCTION

This paper describes a simplified methodology to compare supply and demand-side resources. The *screening curve approach* supplements with load shape information the data contained in a supply curve of conserved energy. In addition, a screening curve contains information on competing supply technologies, such as annualized capital costs, variable costs, and cost per delivered kWh. The information in the screening curve allows policymakers to promptly and conveniently compare the relevant parameters affecting supply and demand-side investment decisions.

While many sophisticated computer models have evolved to account for the load shape impacts of energy efficiency investments, this sophistication has, by and large, not trickled down to spreadsheet-level or back-of-the-envelope analyses. Our methodology allows a simple summary of load shape characteristics based on the output of the more complicated models. It offers many advantages, principal of which is clarity in analyzing supply and demand-side investment choices.

This paper illustrates the uses of screening curves in the least-cost utility planning process. The first section explores the conventional uses of screening curves for presenting information on supply technologies. The second section develops the concepts needed to plot demand-side technologies on a screening curve. The third section uses detailed examples of supply technologies and demand-side programs to create representative supply/demand screening curves.

SCREENING CURVES FOR SUPPLY TECHNOLOGIES

In the past, utility planners used a tool called a "screening curve" for preliminary analysis of the cost of new supply options (EPRI 1986, p.6-4). This curve was obtained from a set of plots for supply options, with each plot showing the capacity factor[1] on the x-axis and annual power plant cost (fuel plus capital) per installed kW on the y-axis. A typical screening curve for supply options is shown in Figure 1 (ignore the conservation programs for now and treat the x-axis as the capacity factor). The y-intercept is the annualized capital cost of the power plant, and the slope of the cost curve for each option represents the variable cost of operating the plant. In this figure, we see that combustion turbines are the cheapest solution at low capacity factor (0 to 20%), but the high operating costs of these plants make them more expensive when operated at a capacity factor greater than 20%. High capital cost baseload plants are only economic when operated at capacity factors greater than 85% in this example.

A power purchase from other utilities or from independent power producers may also be included on a screening curve. The annual fixed cost of the contract is the same as the annualized capital cost of a power plant, while the per kWh cost is analogous to the variable cost of the plant.

The screening curve establishes the envelope within which a supply option will be economic, and reduces the number of options to analyze. Thus, if the projected cost curves of three new supply technologies fell well below the envelope, these options would be worthy of further analysis. This tool, while admittedly a crude one, serves to "screen out" options that cannot possibly be economic. Such screening tools were especially important in the days before the advent of abundant and inexpensive computing power, but they can still be useful as a simple summary of the essential characteristics of supply technologies.

A limitation of this approach is that it is a single year "snapshot", based on certain fuel price assumptions. The curves may be based on current fuel prices or on some levelized estimate of future prices. A levelization procedure may also be used to compensate for projected power plant cost escalation.

CHARACTERISTICS OF ENERGY-EFFICIENCY INVESTMENTS

This section lays the conceptual groundwork for integrating supply and demand side resources on a screening curve. It first presents two of the most widely used measures of conservation's cost effectiveness and describes their advantages. It then describes the *conservation load factor* and its uses.

Evaluating Conservation's Cost

When evaluating energy-efficiency technologies, analysts typically calculate the Cost of Conserved Energy (CCE, in ¢/kWh) and the Cost of Avoided Peak Power (CAPP, in $/kW) (Meier, Wright et al. 1983). Both CCE and CAPP are used in supply curves of conserved energy and avoided peak power, ranked in order of increasing CCE and CAPP. Creating these curves typically involves detailed calculations for dozens or hundreds of conservation options (Krause 1987).

CCE and CAPP are useful because they allow ostensibly consistent comparisons between characteristics of energy conservation and energy supply technologies. The procedure for calculating both quantities involves annualizing the total cost of the conservation technology, and dividing by the number of kWh saved or peak demand (kW) avoided. CCE is analogous to the busbar cost of a power plant (adjusted to represent the cost per *delivered* kWh), while CAPP may be compared to the capital cost of the plant per delivered kW.

1 The capacity factor (range 0 to 1) is defined as the number of kWh generated by a power plant in some time period, divided by the number of kWh that would be generated if the plant operated at rated capacity for that time period.

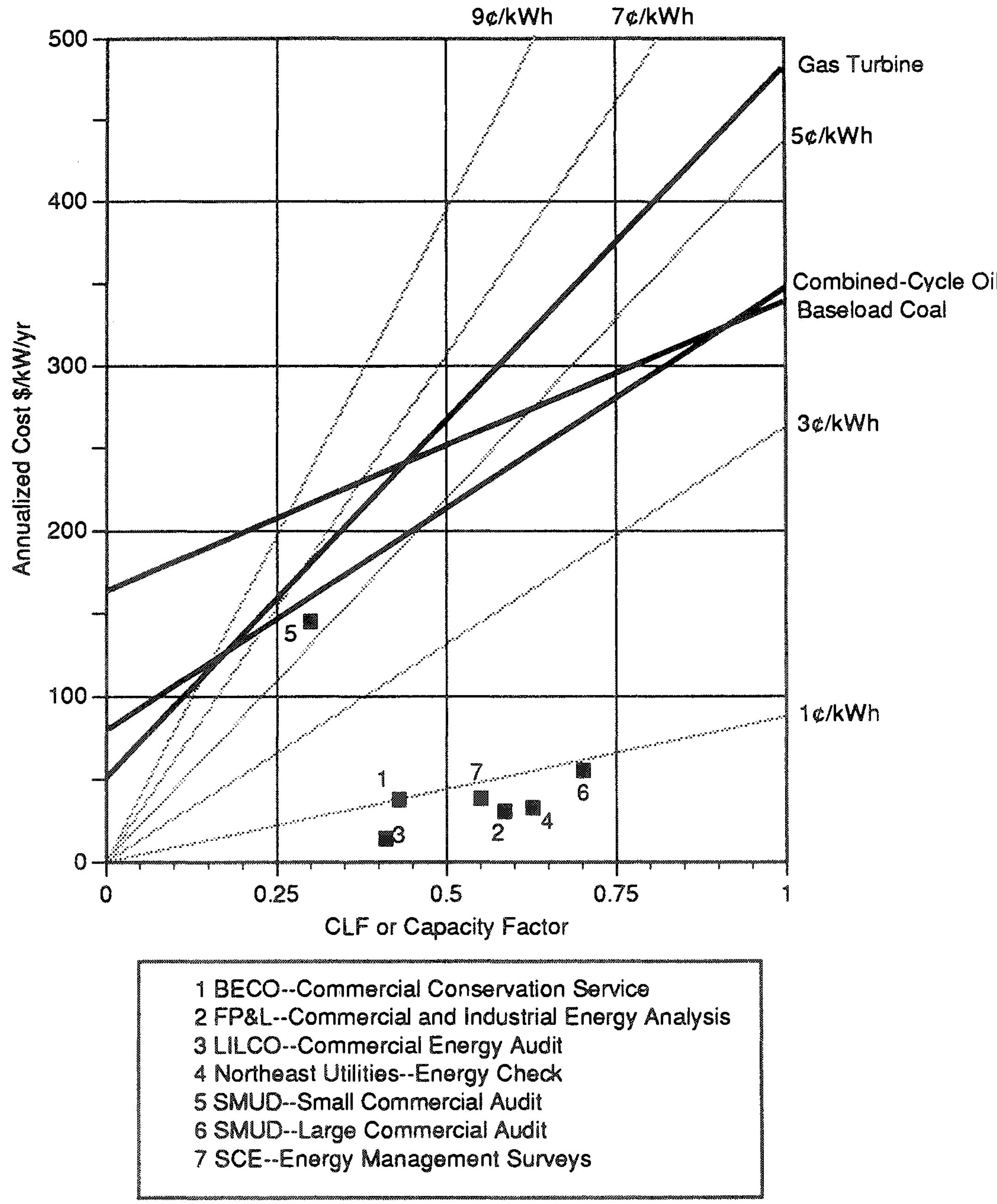

Figure 1. Screening Curve for Commercial Audit Programs
Sources: Conservation Programs--Nadel 1990; Supply Technologies--EPRI 1986

However, it is arbitrary to allocate all of the costs of conservation technologies to peak power savings; this approach reflects a fundamental problem in using CAPP for all but load management technologies. Busbar cost is widely used because it summarizes information about capital costs, fuel costs, and operation of the power plant. CCE is a more useful measure than CAPP in part because its analogue, busbar cost, is more inclusive and general than the corresponding measure of power plant capital cost per installed kW.

Introduction to the Conservation Load Factor

This section introduces a new concept, called the conservation load factor or CLF. Once the CLF is determined through simulation or measurement, it allows straightforward calculation of the peak demand avoided from a given amount of energy savings, as well as the *value of conserved energy*, which can be compared to the CCE. This formulation can be useful in back-of-the-envelope or spreadsheet analyses of conservation measures. The CLF is analogous to the capacity factor, which allows demand and supply-side resources to be plotted side by side on a screening curve, as shown in the next section.

The CLF is defined as:

$$\mathrm{CLF} = \frac{\text{Average Annual Load } \textit{Savings}}{\text{Peak Load } \textit{Savings}} \qquad (1)$$

where average annual load savings is the conservation measure's expected kWh savings divided by 8760 hours, and the peak load savings (i.e., savings at the time of utility peak demand) is based on measured data or on the output of an hourly simulation model. The peak load savings are a function of the utility's load profile, the diversity and shape of end-use loads, and the coincidence of energy savings with peak demand. A conservation technology that saves a constant amount of power on a continuous basis has a CLF of 1.0.

Although the CLF usually ranges from 0 to 1.0, in principle it may exceed one, if a conservation measure saves energy principally in off-peak periods (e.g., variable-speed compressors for air conditioners). The screening curve's abscissa may be extended to account for such measures, even though power plant capacity factors cannot exceed 1.0. A better solution is to plot only those conservation measures with a CLF between 0 and 1 (which are by far the majority) and include the CLFs for all measures in a table that summarizes the essential characteristics of each measure.

The CLF is analogous to both the utility load factor[2] and the power plant capacity factor, and it is related to the more commonly used diversified load factor (DLF). The DLF is calculated as the ratio of the average load of a group of appliances to the measured peak demand of the same set of appliances. If the peak demand is averaged over the hours when the utility needs capacity, the peak load *savings* from a conservation measure can be calculated using the diversified load factors for efficient and inefficient appliances[3].

The demand savings used to calculate the CLF should be the *coincident* demand savings, since only at time of system peak do energy savings improve system reliability. The utility will operate dispatchable supply options with low first costs and high operating costs (such as gas turbines) during those few hours when capacity is needed. Coincidence with peak demand is therefore implicit for these technologies. The CLF must be based on coincident peak demand savings to allow direct comparison to power plant capacity factors. It would be most accurate to use a loss-of-load probability (LOLP)[4] weighted average (over the hours of significant LOLP) of measured or calculated peak demand

---

2 *Defined as (Average System Load)/(Highest System Load).*

3 *The DLF may be different for the efficient appliances because the conservation measure may change the shape of the appliance load curve.*

4 *LOLP is defined as the probability, in any hour, of the load exceeding the available generating capacity. It is a highly non-linear function that tends to be concentrated in the 100 to 500 highest hours of load. For more details, see Kahn (1988), pp.81-86.*

savings in Equation 1, although in practice cruder approximations are often used[5].

Multiplying both numerator and denominator in Equation 1 by 8760 hours gives:

$$CLF = \frac{\text{Annual Energy Savings (kWh)}}{\text{Peak Load Savings (kW)} * \text{8760 hours}} \quad (2)$$

Once the CLF is determined through measurement or calculation of energy and peak demand savings, this equation gives the number of kWh of energy savings to avoid 1 kW of peak demand:

$$CLF * \text{8760 hours} = \frac{\text{Annual Energy Savings}}{\text{Peak Load Savings}} = \frac{\text{kWh}}{\text{kW}} \quad (3)$$

Equation 3 may be used to calculate the *value* of capacity (kW) saved (¢/kWh), given information on the cost per kW of the appropriate proxy power plant (US DOE 1988). For example, suppose the annualized cost of a combustion turbine proxy is $33/kW/yr (adjusted for reserve margin and system losses--see EPRI 1986), and the CLF of a conservHP 2000 (Super Cartridge) (11/6)H2SUCA11.PRS this efficiency measure is worth 2.5¢ (=$33/1314 kWh). A conservation measure with a low CLF will have a high capacity value per kWh, as we expect.

The capacity value can be added to the fuel cost avoided by each kWh (i.e., the short-run marginal cost or avoided cost) to get a *value of conserved energy* (¢/kWh) that can be compared directly to the CCE. A demand-side measure is economic if the value of conserved energy is larger than the CCE.

Once the CLF is determined, equation 3 can be used to calculate the amount of peak demand savings from a given amount of energy savings. Equation 3 also suggests that a close relationship exists between the CLF and the power plant capacity factor. For a baseload plant, one kW that generates 5700 kWh has a capacity factor of 0.65, while a conservation measure that saves 5700 kWh and reduces peak demand by 1 kW has a conservation load factor of 0.65.

5 *One such approximation is to average the load savings over the 200 highest residential or commercial hourly loads; another is to average the savings over the hours of noon - 6 pm in the summer. Many other approximations can be used to account for both diversity and coincidence, all of which are imperfect. They can be improved in accuracy through an iterative process of measurement and simulation.*

INTEGRATING SUPPLY TECHNOLOGIES AND EFFICIENCY PROGRAMS

Capacity factors and CLFs may be used to plot conservation programs[6] on a screening curve, as shown in Figures 1 and 2. All conservation programs are represented by squares, all supply options by dark solid lines. The y-coordinate of the point representing a conservation program is the annualized additional capital and maintenance cost[7] of the program per kWh saved (which has nothing to do with the operating cost of the appliance). The x-coordinate equals the CLF or the capacity factor.

The three new conventional supply options shown in Figures 1 and 2 produce a representative screening curve, which may be seen as the upper limit to cost-effective conservation resources. A conservation measure is then attractive if its point falls below the boundary for the corresponding electricity supply technology. The light lines starting from the origin (lines of constant ¢/kWh) represent the short-run marginal cost (SRMC) of energy from existing generating plants, with zero capital costs (the plants are already purchased)[8]. These lines also represent the cost of conserved energy or cost per delivered kWh for demand and supply options falling on that line.

6 *For examples of how to plot specific conservation* technologies *on this type of graph, see Koomey et. al. (1989).*

7 *Designers of an integrated screening curve must decide which cost perspective they wish to illustrate (e.g., utility or societal). In this paper, we adopt the societal perspective, but avoid the added complication of estimating the externalities associated with electricity production. The subtleties of defining these perspectives have been addressed in Krause and Eto (1988).*

8 *Using one number to represent the marginal costs over the entire year is a crude approximation, but it is entirely in the spirit of the screening curve approach.*

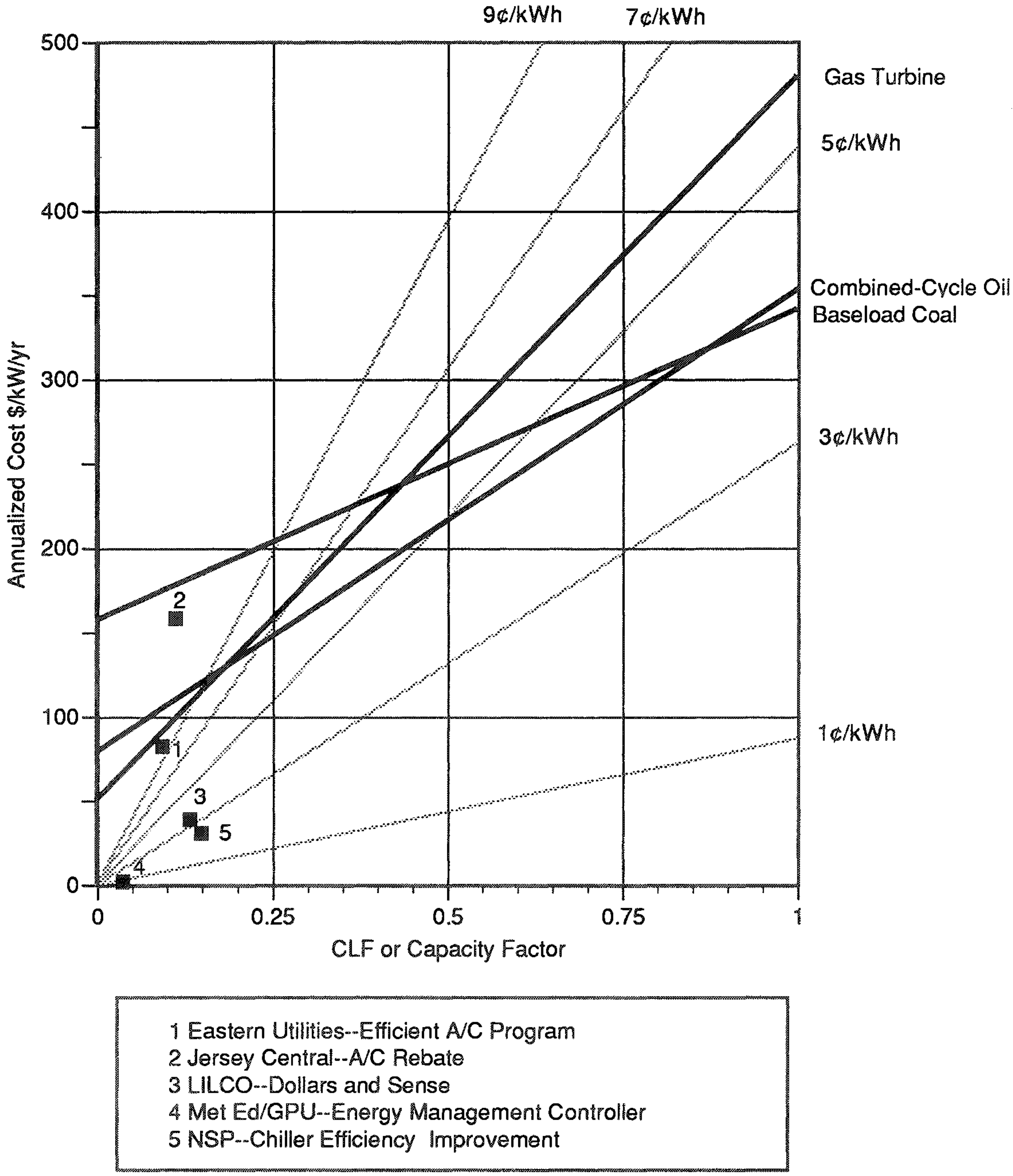

Figure 2. Screening Curve for Commercial HVAC Conservation Programs
Sources: Conservation Programs--Nadel 1990; Supply Technologies--EPRI 1986.

A conservation measure with a CLF close to zero saves a larger amount of peak demand than a measure with a CLF close to 1, and thus has a larger capacity value per kWh. The screening curve shows that even measures with relatively high CCEs (such as central air conditioner efficiency improvements) may still be economic if the energy savings is concentrated in peak hours (i.e., the CLF is close to zero). The screening curve accurately portrays the tradeoff between high CCE and low CLF.

The particular characteristics of each program or technology are not as important for our purposes, since we care more about the method for plotting them. We discuss these characteristics below. Table 1 and Koomey et al. (1989) contains technical details about the supply technologies shown in Figures 1 and 2, while Nadel (1989) contains similar information for the efficiency programs.

Supply Options

This section presents some of the assumptions used to calculate the characteristics of supply options shown Table 1 and in Figures 1 and 2. In all cases, we used a 6.1 percent real discount rate, a T&D loss factor of 6 percent, and a reserve margin of 20 percent. We adjusted all costs to 1988 dollars using the consumer price index. We took data for the three conventional fossil fuel technologies from the 1986 EPRI Technical Assessment Guide (EPRI 1986). We used levelized, base-case natural gas, oil and coal price forecasts, calculated using fuel price forecasts for the period 1988-2000 from the U.S. Department of Energy (US DOE 1989).

Two of the following three parameters need to be specified to plot a supply technology on Figures 1 and 2: total annualized variable cost in \$/kW/yr (as a function of capacity factor), annualized fixed cost (\$/kW/yr), and/or busbar cost for continuous operation (¢/kWh)[9]. The variable cost may be matched to the slope of the appropriate SRMC line emanating from the origin. The annualized fixed cost may be plotted for a point at zero capacity factor (on the y-axis), while the busbar cost for continuous operation may be plotted for a point at capacity factor equals 100% (using the appropriate SRMC lines).

Efficiency Programs

Figure 1 shows the results from seven audit conservation programs, and Figure 2 shows results from five HVAC conservation programs, from Nadel (1989). We choose only those programs from Nadel's survey that reported cost of conserved energy, total energy savings, and coincident peak demand savings. We have made no attempt to correct for different discount rate assumptions.

These two Figures demonstrate the usefulness of the screening curve approach. Figure 1 shows that commercial audit programs are comparable in their load shape impacts to intermediate or baseload power plants, with conservation load factors between 30% and 70%. These programs, with one exception, save energy at a cost of conserved energy (CCE) less than or equal to 1¢/kWh. Figure 2 shows that HVAC conservation programs (principally for air conditioning) are comparable to peaking generation, with CLFs between 4% and 15%. The CCEs are less uniform than for audit programs, and are greater than or equal to 1¢/kWh. Even with these higher CCEs, all but one of the conservation programs are competitive with or superior to the generation alternative (a gas-fired combustion turbine).

UTILITY INVESTMENT DECISIONS

When analyzing a utility's least-cost plan, regulators and other analysts can use a supply curve of conserved energy to estimate the *amount* of energy savings available, and can use a screening curve to compare the costs and load shape characteristics of efficiency programs to those of competing supply technologies. Once the screening curve is created, analysts can quickly determine which efficiency measures have CCEs below the delivered cost of electricity generation for peaking and baseload resources. Efficiency measures can be combined in "packages" that save the same amount of energy as the comparable power plant would generate, thus facilitating comparisons.

CONCLUSIONS

Screening curves supplement the information contained in supply curves of conserved energy. They incorporate and summarize CCE and load shape characteristics for conservation investments, and cost per delivered kWh and capacity factors for supply technologies. They are a new and useful tool for conducting least-cost utility planning analyses.

---

9 *All these costs must be adjusted to account for transmission and distribution losses; in addition, annualized fixed costs must be adjusted to account for reserve margin needed to preserve adequate reliability. Thus they are costs per* delivered *kW or per* delivered *kWh.*

Table 1. Characteristics of Supply Technologies

Parameter	CT Gas	Combined-Cycle Oil	Baseload Coal
Fixed Costs			
Lifetime (Years)	30	30	40
Capital Recovery Factor	0.073	0.073	0.067
Capital Cost ($/kW)	348	618	1421
Annualized Capital Cost ($/kW/yr)	25.58	45.38	95.66
Fixed O&M ($/kW/yr)	0.506	8.315	22.585
Sum of Fixed Costs ($/kW/yr)	*26.08*	*53.69*	*118.25*
T&D + Reserve Margin Adjustment	1.272	1.272	1.272
Adjusted Fixed Costs ($/kW/yr)	*33.18*	*68.30*	*150.41*
Variable Costs			
Incremental O&M (¢/kWh)	0.48	0.21	0.56
Heat Rate (Btus/kWh)	13900	8440	9660
Fuel Price ($/MMBtu)	3.04	3.58	1.67
Fuel Cost (¢/kWh)	4.2	3.0	1.6
Sum of Variable Costs (¢/kWh)	*4.7*	*3.2*	*2.2*
T&D Adjustment	1.06	1.06	1.06
Adjusted Variable Costs (¢/kWh)	*5.0*	*3.4*	*2.3*
Delivered Cost @ 100% Cap.Factor (¢/kWh)	*5.4*	*4.2*	*4.0*
Assumptions	T&D Losses	Reserve Margin	Real Disc. Rate
	1.06	1.2	6.1%

Sources: Capital and O&M costs--EPRI 1986; Fuel Prices--levelized 1988-2000 from US DOE 1989; CT = combustion turbine; All Costs in 1988 $

ACKNOWLEDGMENTS

This paper has benefited from discussions with Alan Comnes (currently at the CPUC), and with colleagues at Lawrence Berkeley Laboratory: Joe Eto, Jeff Harris, Ed Kahn, Chris Marnay, Jim McMahon, Evan Mills, Ed Vine.

The work described in this paper was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Systems Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

REFERENCES

EPRI, Electric Power Research Institute. 1986. *TAG-Technical Assessment Guide: Vol. 1: Electricity Supply-1986.* EPRI. EPRI P-4463-SR. December 1986.

Kahn, Edward. 1988. *Electric Utility Planning and Regulation*. Washington, D.C.: American Council for an Energy-Efficient Economy.

Koomey, Jonathan, Arthur H. Rosenfeld, and Ashok K. Gadgil. 1989. *Conservation Screening Curves for Comparing Investments in Energy Efficiency and Electric Capability*. Lawrence Berkeley Laboratory. LBL-27286. June 1989 (To appear in Energy Policy, September 1990).

Krause, Florentin, et al. 1987. *Analysis of Michigan's Demand-Side Electric Resources in the Residential Sector* (Prepared for the Michigan Electricity Options Study). Lawrence Berkeley Laboratory. Report # LBL-23025. May 1987.

Krause, Florentin, and Joseph Eto. 1988. *Least-Cost Utility Planning: A Handbook for Public Utility Commissioners (v.2): The Demand Side: Conceptual and Methodological Issues*. National Association of Regulatory Utility Commissioners, Washington, DC. December 1988.

Meier, Alan, Jan Wright, and Arthur H. Rosenfeld. 1983. *Supplying Energy Through Greater Efficiency*. Berkeley, California: University of California Press.

Nadel, Steven. 1989. *Lessons Learned: A Review of Utility Experience with Conservation and Load Management Programs for Commercial and Industrial Customers*. New York State Energy Research and Development Authority. March 1990.

U.S. Department of Energy. 1988. *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets*. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. DOE/CE-0239. November 1988.

U.S. Department of Energy. 1989. *Annual Energy Outlook: Long-Term Projections 1989.* Energy Information Administration. DOE/EIA-0383(89).